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D.3.6 Nearshore Wave Dimensions

As waves propagate near the shore and over a flooded area, they undergo transformations caused by local winds, interaction with the bottom, and physical features such as buildings, trees, or marsh grass. Figure D-44 illustrates the effects at a transect of obstructions on the wave crest elevations and the flood zone. For Great Lakes coasts, the effects must be calculated objectively along each transect, from the Low Water Datum to the flooding limit. Fundamental analysis of wave effects for an FIS is provided by the FEMA computer program Wave Height Analysis for Flood Insurance Studies (WHAFIS). The program calculates wave heights, wave crest elevations, flood hazard zone designations, and the location of zone boundaries along a transect. The current program version for the Great Lakes region, WHAFIS 3.0 GL, incorporates windspeeds appropriate to Great Lakes events (40 mph over fully exposed waters and 30 mph for inland waters or marsh).

Wave description for an FIS addresses the controlling wave height, equal to 1.6 times the significant wave height common as a basic wave description, with the dominant (or spectral peak) wave period. Significant wave height is the average height of the highest one-third of waves, and controlling wave height is slightly less than average height of the highest one percent of waves in storm conditions. The wave condition of interest is that expected to accompany the 1-percent-annual-chance flood.

Within WHAFIS, a wave action conservation equation governs wave regeneration caused by wind and wave dissipation caused by marsh plants. This equation is supplemented by the conservation of waves equation, which expresses the spatial variation of the wave period at the peak of the wave spectrum. The wave energy (i.e., wave height) and wave period respond to changes in wind conditions, water depths, and obstructions as a wave propagates. These equations are solved as a function of distance along the transect. Technical details are fully documented in the WHAFIS program documentation (FEMA, September 1988).

The current NFIP treatment of wave dimensions has resulted from periodic upgrades of technical procedures, with the original basis being the NAS methodology documented in *Methodology for Calculating Wave Action Effects Associated with Storm Surges* (NAS, 1977). The NAS methodology, which was developed to be suitable for manual computations, accounts for varying fetch lengths, barriers to wave transmission, and the regeneration of waves over flooded land areas. Several aspects of usual Great Lakes situations suggest that simplified analysis, considering only water depth and thin vertical barriers, might give a useful outline of wave effects for some sites.

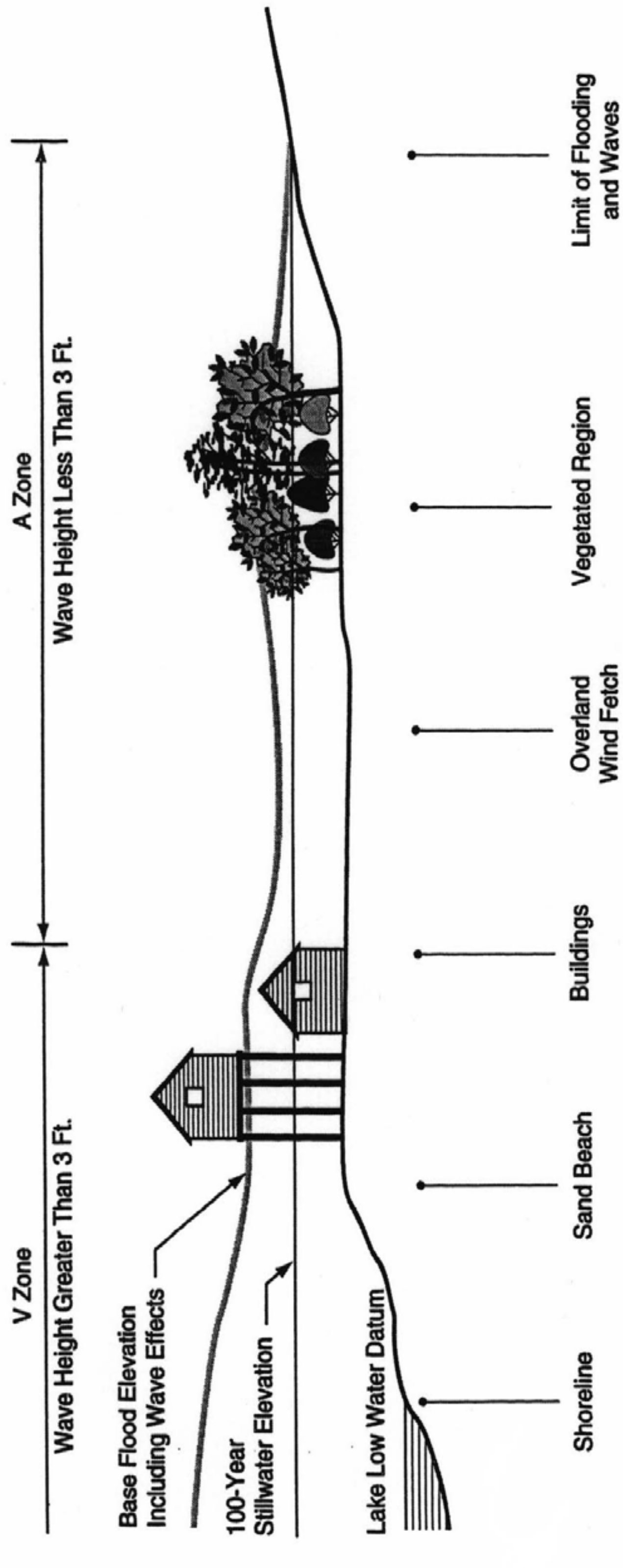

Figure D-44. Schematic Wave Effects along a Coastal Transect.

[February 2002]

D.3.6.1 Simplified Wave Height Analysis

The potential usefulness of the simplified wave analysis method for treating 1-percent-annual-chance flood waves is suggested by certain aspects of the Great Lakes situation: the relatively low windspeeds, reducing the intensity of wave regeneration; the relatively simple eroded geometries, which are generally featureless lakeward of the ultimate flood barrier; the absence of barrier islands and back bays so that another flood source or elevation is seldom encountered; and the typical narrowness of the Coastal High Hazard Area. This method would not be appropriate where the transect includes coastal wetlands, other land cover providing appreciable flow resistance, or an extensive lowland area liable to flooding. Before any wave analysis, there must be confirmation that sizable waves likely propagate towards shore during the local 1-percent-annual-chance flood.

All elements of this treatment are extracted from the basic NAS methodology (Dawdy & Maloney, 980; FEMA, February 1981; NAS, 1977), with wave heights entirely regulated by local water depth. The estimated flood elevation (Z) is defined by wave action accompanying the flood, with the majority of the waveform in the crest above the 1-percent-annual-chance SWEL (S):

$$Z = S + 0.7\ H \tag{3}$$

where H is the local controlling wave height. A bound to H is given by wave breaking in shallow water, with the upper limit

$$H_* = 0.78\ d \tag{4}$$

where local water depth (d) equals (S-G), G being ground elevation. Combining these relations, local ground elevation constrains the flood elevation to an upper limit of

$$Z_* = S + 0.55\ d \tag{5}$$

Equation (4) implies that a minimum water depth of 3.85 feet is required for the 3-foot wave height characterizing a V Zone.

An obstruction on the transect may conveniently be treated as a thin barrier if flooding occurs to the same S on each side. Wave transmission is assumed to occur only if the barrier top elevation (C) is below S plus one-half the incident wave height (H_i). Transmitted wave height is

$$H_t = 0.5\ H_i + B \tag{6}$$

where B = ½[0.78 (S-C)] if the barrier is submerged, but B=[(S-C)] otherwise; the upper limit of $H_t = H_i$ occurs when H_i is less than [0.78 (S-C)], requiring that H_i is not depth-limited. Transmitted wave height beyond the barrier remains limited by ground elevation on the landward side of the barrier (G_t), through Equation (2), just as incident wave height is limited by ground elevation on the lakeward side (G_i). With engineering judgment, wave obstructions other than walls might be represented by proper choices of G_i, C, and G_t in this procedure.

Figure D-45 presents an idealized numerical example demonstrating estimated wave heights, flood elevations, and flood zones. Note that varying elevations of depth-limited wave crests mirror the ground slopes.

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D.3.6.2 Use of WHAFIS 3.0 GL Model

Careful preparation and input of required site data are necessary in using WHAFIS. Like the other coastal treatments, the WHAFIS model considers the study area by representative transects. For WHAFIS, transects must be defined considering major topographic, vegetative, and cultural features. The transect, referenced to NGVD29, begins at the local elevation of Low Water Datum (Table D-13) and proceeds landward until either the ground elevation exceeds the SWEL or another flooding source is encountered.

Fundamental specifications for WHAFIS input include the 1-percent-annual-chance flood SWEL and a description of waves existing at the transect start. The wave description provides for an overwater fetch length, an initial significant wave height, or an initial period of dominant waves. In most Great Lakes applications, the wave period should be the input description, because that parameter is readily available from information about offshore waves (see Subsection D.3.2.6).

The Mapping Partner shall locate transects on the work maps and plot the transect ground profile from the topographic data, adjusted for erosion. The Mapping Partner shall ensure that each transect has all the input data identified on the profile plot for ease of input coding. The Mapping Partner also shall identify the location, height, and width of elongated manmade structures and show them as part of the ground profile, after confirming the structure's stability under forces of the 1-percent-annual-chance flood (see Subsection D.3.3).

Buildings are specified on the transect as rows perpendicular to the transect. Because buildings are not always situated in perfect rows, the Mapping Partner shall exercise judgment to determine which buildings can be represented by a single row. The required input value for each row of buildings is the ratio of open space to total space. This is simply the sum of distances between buildings in a row, divided by the total length of that row.

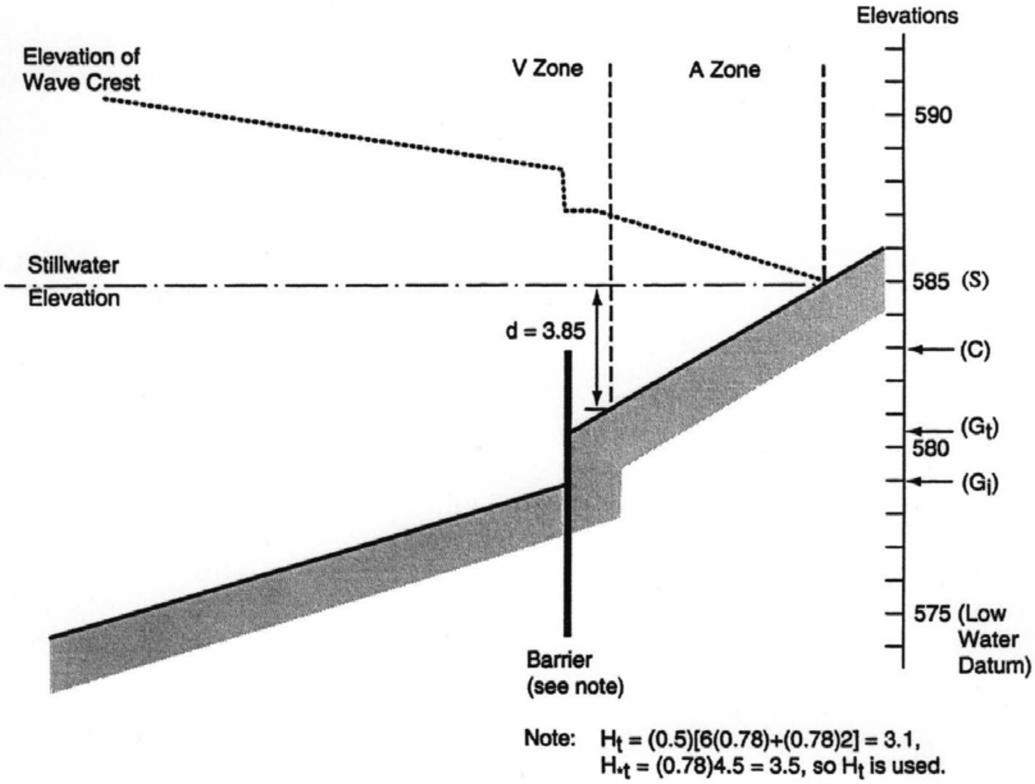

Figure D-45. Schematic Example of Simplified Wave Height Analysis Regulated by Local Water Depth, with All Indicated Quantities in Feet.

The first row or two of buildings along the shoreline is not always to be considered as obstructions. During a 1-percent-annual-chance flood, it is sometimes appropriate to assume that if they are not elevated on pilings, these buildings will be destroyed before the peak of the flood occurs. If they are elevated, the waves should propagate under the structures with minimal reduction in height. The Mapping Partner shall contact local officials to obtain typical construction methods and the lowest elevations of structure.

The WHAFIS program has two routines for vegetation: one for rigid vegetation that can be represented by an equivalent "stand" of equally spaced circular cylinders (NAS, 1977) and one for marsh vegetation that is flexible and oscillates with wave action (FEMA, 1984). For either type, considerable care is required in selecting representative parameters and in ruling out that the vegetation will be intentionally removed or that effects during a storm would be markedly reduced through erosion, uprooting, or breakage.

For the areas of rigid vegetation located on the transect, the required input values are the drag coefficient, CD; mean wetted height, h; mean effective diameter, D; and mean horizontal spacing, b. The value of CD should vary between 0.35 and 1.0, with 1.0 being used in most cases of wide vegetated areas. When the vegetation is in a single stand, a value of 0.35 should be used. Representative values for h, D, and b can be obtained from stereoscopic aerial photographs or by field surveys. Various guides for terrain analysis can provide procedures for estimating these values from aerial photographs. Table D-19 provide a useful procedure developed from Terrain Analysis Procedural Guide for Vegetation (Messmore, Vogel, & Pearson, 1979).

For marsh vegetation, a more complicated specification is required for completeness, and the eight parameters used to describe the attenuation properties of a specific vegetation type are explained in Table D-20.

WHAFIS includes considerable basic information on eight common types of seacoast marsh plants listed in Table D-21 (FEMA, 1984; FEMA, 1989), but among these, apparently only the *Juncus* species are likely to occur in the freshwater marshes on the Great Lakes. For vegetation not listed in Table D-21, the Mapping Partner shall input the geometrical parameters to WHAFIS.

At lakeshore elevations that are seldom flooded and thus are important for the 1-percent-annual-chance flood, a great diversity of wetland vegetation can occur along with upland vegetation species. Prevalent marsh plants at relatively high elevations (Levels Reference Study Board) may include combinations of grasses (*Phalaris arundinacea*, *Calamagrostis canadensis*), sedges (*Carex lacustris*, *C. rostrata*, *C. stricta*, *C. lasiocarpa*), rushes (*Juncus canadensis*, *J. effusus*), or cattails (*Typha* varieties). The Mapping Partner shall specify each existing type of vegetation s, along with its fractional coverage in any sizable patch; a patch of at least 10,000 square feet (0.09 hectare) can affect wave heights appreciably.

Table D-19. Procedure for Vegetation Analysis Using Stereoscopic Aerial Photographs.

1. Using the parallax bar or wedge, determine the height of three representative trees and compute the average height, h.

2. Locate three representative tree crowns, measure the diameters, and compute the average crown diameter, CD.

3. Determine the type of vegetation and calculate the stem diameter, D, using the following formulae:

Southern Pines	D (inches) = 5 + 0.5 CD (feet)
Eastern Hardwoods, Northern Pines and Others	D (inches) = 0.75 CD (feet)

4. Based on the scale of the aerial photographs, determine the diameter of a circle containing 0.08 hectares using Table 4. Place the circle on the photograph, over a representative area of trees, and count the number of trees, n, in the circle. A magnifier may be needed. More than one area can be counted and an average used for n. Calculate the number of trees per hectare, N, using the following formula:

$$N = \frac{n}{0.08}$$

5. Determine the horizontal spacing between trees using the following formula:

$$b\ (\text{feet}) = 3.28\ \left(\frac{12732}{N}\right) - \frac{D\ (\text{inches})}{12}$$

Table D-19. Procedure for Vegetation Analysis Using Stereoscopic Aerial Photographs (Cont.)

CIRCLE DIAMETERS
.08 HECTARE AREA, (1/5 ACRE)
(800 Square Meters, 8712 Square Feet)

PHOTO SCALE	.08 HECTARE CIRCLE	CIRCLE DIAMETER INCHES	MILLIMETERS
1:5,000	○	.253	6.38
1:6,000	○	.211	5.32
1:7,000	○	.1805	4.56
1:8,000	○	.158	3.99
1:9,000	○	.140	3.55
1:10,000	○	.126	3.192
1:11,000	○	.115	2.90
1:12,000	○	.105	2.66
1:13,000	○	.092	2.46
1:14,000	○	.090	2.28
1:15,000	○	.084	2.13
1:16,000	○	.079	1.99
1:17,000	○	.074	1.88
1:18,000	○	.070	1.77
1:19,000	○	.067	1.68
1:20,000	○	.063	1.60
1:21,000	○	.060	1.52
1:22,000	○	.057	1.45
1:23,000	○	.055	1.39
1:24,000	○	.053	1.33
1:25,000	○	.051	1.28

Table D-20. Marsh Plant Parameters

PARAMETER	EXPLANATION
C_D	Effective drag coefficient. Includes effects of plant flexure and modification of the flow velocity distribution. Default value is 0.1, usually appropriate for marsh plants without strong evidence to the contrary.
F_{cov}	Fraction of coverage. A default value is calculated by the program so that each plant type in the transect is represented equally, and the sum of the coverage for the plant types is equal to 1.0.
h	Unflexed stem height (feet). The stem height does not include the flowering head of the plant, the inflorescence.
N	Number density. Expressed as plants per square foot. The relationship to the average spacing between plants, b, can be expressed as $N = 1/b^2$.
D_1	Base stem diameter (inches). Default value may be determined from stem height and regression equations built into the program.
D_2	Mid stem diameter (inches). Default value may be determined from plant type and base stem diameter.
D_3	Top stem diameter (inches), at the base of the inflorescence. Default value may be determined from plant type and base stem diameter.
CA_b	Ratio of the total frontal area of the cylindrical portion of the leaves to the frontal area of the stem below the inflorescence. Default value may be determined from the plant type.

Table D-21. Abbreviations of Marsh Plant Types Used in WHAFIS

SPECIES OR SUBSPECIES	ABBREVIATION
Cladium jamaicense (saw grass)	CLAD
Distichlis spicata (salt grass)	DIST
Juncus gerardi (black grass)	JUNM
Juncus roemerianus (black needlerush)	JUNR
Spartina alterniflora (medium saltmeadow cordgrass)	SALM
Spartina alterniflora (tall saltmeadow cordgrass)	SALT
Spartina cynosuroides (big cordgrass)	SCYN
Spartina patens (saltmeadow grass)	SPAT

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D.3.6.3 Input Coding

After all the necessary input data have been identified on the transect, the Mapping Partner shall divide the transect into continuous segments, each representing a single open fetch or obstruction. Fetches are flooded areas with no obstructions, such as dunes, manmade barriers, buildings, and vegetation. The Mapping Partner shall subdivide fetches at points where the ground elevation abruptly changes and in the transition area of changing SWELs. The Mapping

Partner shall subdivide obstructions at the transect's seaward edge to more accurately model the wave dissipation. Rigid vegetation is to have two to three seaward segments extending 10 to 50 feet, and the first two or three rows of buildings are to have a segment for each row. Marsh vegetation will be subdivided by the WHAFIS model, and thus segmented input is not necessary.

The Mapping Partner shall enter the necessary data using 11 line types, including the Title line. The ten remaining lines each describe a certain type of fetch or obstruction, listed as follows:

- The IE (Initial Elevation) line describes the initial overwater fetch and the initial SWELs.
- The IF (Inland Fetch) and OF (Overwater Fetch) lines define the endpoint stationing and elevation of inland and overwater fetches, respectively.
- Obstructions are categorized either as buildings (BU line), rigid vegetation (VE line), marsh vegetation (VH and MG lines), dunes and other natural or manmade elongated barriers (DU line), or areas where the ground elevation is greater than the 1-percent-annual-chance SWEL (AS line).
- The ET (End of Transect) line enters no data but indicates the end of the input data.

Each line has an alphanumeric field describing the type of input for that line, followed by ten numeric fields describing the parameters.

To ensure proper modeling, the Mapping Partner shall enter all segments of each transect either as fetches or obstructions, with one input line required for each fetch or obstruction segment. The first two columns of each line identify the type of fetch or obstruction. The remaining 78 columns consist of one field of six columns followed by nine fields of eight columns. The Mapping Partner shall right-justify the numbers in any data field only if no decimal point is used. Decimal points are permitted but not required. The end point of one fetch or obstruction is the beginning of the next. The first two numeric fields of each line are used to read in the stationing (measured in feet from the beginning of transect) and elevation (in feet) of the end point. The last two fields used on each line are for entering new SWELs. An interpolation is performed within a transect segment starting at the closest station with an input SWEL. This interpolation uses the new SWEL input at the end point of the segment and the SWEL input at a previous segment. If these fields are blank or zero, the SWELs remain unchanged.

The input data requirements are summarized below for each line type. The Title line must be the first line, followed by the IE line, followed by any combination of the various fetch and obstruction lines. The ET line must be the last card entered for the transect. A blank line must follow to signify the end of the run. If multiple transects are being run, the Title line for the next transect will follow the blank line. All units are in feet unless otherwise specified.

<u>TITLE Line (Title)</u>

This line is required and must be the first input line.

DATA FIELD	COLUMNS	CONTENTS OF DATA FIELDS
0	1-2	Blank
1-10	3-80	Title information centered about column 40

IE Line (Initial Elevations)

This line is required and must be the second input line. This line is used to begin a transect at the shoreline and compute the wave height arising through the overwater fetch.

DATA FIELD	COLUMNS	CONTENTS OF DATA FIELDS
0	1-2	IE
1	3-8	Stationing of end point of initial overwater fetch in feet (zero at beginning of transect)
2	9-16	Ground elevation at end point in feet (usually Low Water Datum at beginning of transect)
3	17-24	Overwater fetch length (miles), if wave condition is to be calculated. Values of 24 miles or greater yield identical results.
4	25-32	10-percent-annual-chance SWEL in feet
5	33-40	1-percent-annual-chance SWEL in feet
6	41-48	Initial wave height; a blank or zero causes a default to a calculated wave height
7	49-56	Initial wave period (seconds); a blank or zero causes a default to a calculated wave period. The period is usually the most convenient wave specification for Great Lakes cases.
8-10	57-80	Not used

AS Line (Above Surge)

This line is used to identify the end point of an area with ground elevation greater than the 1-percent-annual-chance SWEL (such as a high dune or land mass). It is used when the ground surface temporarily rises above the 1-percent-annual-chance SWEL. The line immediately preceding the AS line must enter the stationing and elevation of the point at which the ground elevation first equals the 1-percent-annual-chance SWEL. The SWEL on the leeward side may be different from the SWEL on the windward side. The ground elevation entered on the AS line must equal the SWEL that applies to the leeward side of the land mass. The computer calculations will be terminated if a ground elevation greater than the 1-percent-annual-chance SWEL is encountered.

DATA FIELD	COLUMNS	CONTENTS OF DATA FIELDS
0	1-2	AS
1	3-8	Stationing at end point in feet of area above 1-percent-annual-chance SWEL
2	9-16	Ground elevation in feet at end point
3	17-24	A blank or zero indicates no change to the 10-percent-annual-chance SWEL; otherwise new 10-percent-annual-chance SWEL
4	25-32	A blank or zero indicates no change to the 1-percent-annual-chance SWEL; otherwise new 1-percent-annual-chance SWEL
5-10	33-80	Not used

<u>BU Line (Buildings)</u>

This line enters information needed to compute wave dissipation at each group of buildings.

DATA FIELD	COLUMNS	CONTENTS OF DATA FIELDS
0	1-2	BU
1	3-8	Stationing of end point in feet of group of buildings
2	9-16	Ground elevation at end point in feet
3	17-24	Ratio of open space between buildings to total transverse width of developed area
4	25-32	Number of rows of buildings
5	33-40	A blank or zero indicates no change to 10-percent-annual-chance SWEL; otherwise new 10-percent-annual-chance SWEL
6	41-48	A blank or zero indicates no change to 1-percent-annual-chance SWEL; otherwise new 1-percent-annual-chance SWEL
7-10	49-80	Not used

<u>DU Line (Dune)</u>

This line enters information necessary to compute wave dissipation at substantial sand dunes and other natural or manmade elongated barriers (e.g., levees, seawalls).

DATA FIELD	COLUMNS	CONTENTS OF DATA FIELDS
0	1-2	DU
1	3-8	Stationing at top of dune or barrier in feet
2	9-16	Elevation at top of dune or barrier in feet
3	17-24	A blank or zero indicates a dune or other natural barrier; any other number indicates a seawall or other manmade barrier
4	25-32	A blank or zero indicates no change to 10-percent-annual-chance SWEL; otherwise new 10-percent-annual-chance SWEL
5	33-40	A blank or zero indicates no change to 1-percent-annual-chance SWEL;

DATA FIELD	COLUMNS	CONTENTS OF DATA FIELDS
		otherwise new 1-percent-annual-chance SWEL
6-10	41-80	Not used

IF Line (Inland Fetch)

This line enters the parameters necessary to compute wave regeneration through inland fetches and over shallow inland waterbodies. The IF regeneration is computed using overland wind speed of 30 mph for Great Lakes floods.

DATA FIELD	COLUMNS	CONTENTS OF DATA FIELDS
0	1-2	IF
1	3-8	Stationing at end point of fetch in feet
2	9-16	Ground elevation at end point in feet
3	17-24	A blank or zero indicates no change to 10-percent-annual-chance SWEL; otherwise new 10-percent-annual-chance SWEL
4	25-32	A blank or zero indicates no change to 1-percent-annual-chance SWEL; otherwise new 1-percent-annual-chance SWEL
5-10	33-80	Not used

OF Line (Overwater Fetch)

This line enters the parameters necessary to compute wave regeneration over large bodies of water (i.e., large lakes, bays) using overwater wind speed of 40 mph for Great Lakes floods. If an inland waterbody is sheltered and has a depth of ten feet or less, the IF line calling for overland wind speeds should be used.

DATA FIELD	COLUMNS	CONTENTS OF DATA FIELDS
0	1-2	OF
1	3-8	Stationing at end point of fetch in feet
2	9-16	Ground elevation at end point in feet
3	17-24	A blank or zero indicates no change to the 10-percent-annual-chance SWEL; otherwise new 10-percent-annual-chance SWEL
4	25-32	A blank or zero indicates no change to 1-percent-annual-chance SWEL; otherwise new 1-percent-annual-chance SWEL
5-10	33-80	Not used

VE Line (Vegetation)

This line enters parameters necessary to compute wave dissipation due to rigid vegetation stands.

DATA FIELD	COLUMNS	CONTENTS OF DATA FIELDS
0	1-2	VE
1	3-8	Stationing at end point of vegetation in feet
2	9-16	Ground elevation at end point in feet
3	17-24	Mean effective diameter of equivalent circular cylinder in feet
4	25-32	Average actual height of vegetation in feet
5	33-40	Average horizontal spacing between plants in feet
6	41-48	Drag coefficient; a blank or zero causes a default to 1.0
7	49-56	A blank or zero indicates no change to 10-percent-annual-chance SWEL; otherwise new 10-percent-annual-chance SWEL
8	57-64	A blank or zero indicates no change to 1-percent-annual-chance SWEL; otherwise new 1-percent-annual-chance SWEL
9-10	65-80	Not used

<u>VH Line (Vegetation Header for Marsh Grass)</u>

Marsh grass is often part of a plant community that may consist of several plant types. The VH line is used to enter data that apply to all plant types modeled in the transect segment. To enter data for each plant type, MG lines for each plant type must follow the VH line.

DATA FIELD	COLUMNS	CONTENTS OF DATA FIELDS
0	1-2	VH
1	3-8	Stationing at end point of marsh vegetation segment in feet
2	9-16	Ground elevation at end point in feet
3	17-24	Reg_p, number of the primary seacoast region for default plant parameters. Leave blank for Great Lakes computations.
4	25-32	Wt_p, weighting factor for the primary seacoast region. Not applicable for Great Lakes analyses.
5	33-40	Reg_s, number of secondary seacoast region. Not applicable for Great Lakes analyses.
6	41-48	N_{p1}, number of plant types; range is 1 to 10, inclusive. One MG line is required for each plant type.
7	49-56	A blank or zero indicates no change to the 10-percent-annual-chance SWEL; otherwise new 10-percent-annual-chance SWEL
8	57-64	A blank or zero indicates no change to the 1-percent-annual-chance SWEL; otherwise new 1-percent-annual-chance SWEL
9	65-72	Not used
10	73-80	This field is for overriding the default method of averaging flood hazard factors in A Zones; if 1 in column 80, averaging process begins or ends at end of vegetation segment; otherwise, default averaging method is used

MG Line (Marsh Grass)

This line is used to enter data for a particular plant type. The first MG line must be preceded by a VH line. For the common seacoast marsh grasses listed in Table D-21, potentially useful default values are supplied in Table D-22. If a plant type not listed in the table is used, then appropriate data must be developed for Fields 2-9.

DATA FIELD	COLUMNS	CONTENTS OF DATA FIELDS
0	1-2	MG
1	5-8	Marsh plant type abbreviation (see Table 10)
2	9-16	C_D, effective drag Coefficient; default value is 0.1
3	17-24	F_{cov}, decimal fraction of vegetated area to be covered by this plant type; a blank or zero causes a default to be calculated so that each plant type is represented equally
4	25-32	h, mean unflexed height of stem (feet); for marsh plants, the inflorescence is not included
5	33-40	N, number of plants per square foot
6	41-48	D_1, base stem diameter (inches)
7	49-56	D_2, mid stem diameter (inches)
8	57-64	D_3, top stem diameter (inches)
9	65-72	CA_b, ratio of the total frontal area of cylindrical part of leaves to frontal area of main stem
10	73-80	Not used

ET Line (End of Transect)

This line is required and must be the last input card because it identifies the end of input for the transect.

DATA FIELD	COLUMNS	CONTENTS OF DATA FIELDS
0	1-2	ET
3-10	3-80	Not used

Table D-12. Significant Marsh Plant Types in Each Seacoast Region and WHAFIS Default Regional Plant Parameter Data

REGION NO.	1	2	3	4	5	6	7	8
REGION NAME:	NORTH ATLANTIC	MID-ATLANTIC	SOUTH ATLANTIC	SOUTH FLORIDA	NORTHEASTERN GULF	DELTA PLAIN	CHENIER PLAIN	SOUTH TEXAS
CLAD	---	---	---	7.50(+) 0.0656 6	6.00(2) 0.0260 6	---	---	---
DIST	---	0.78(1) 0.0039 211	1.00(1) 0.038 243	1.00(+) 0.0038 248	--- ---	1.08(4) 0.0035 102	1.08(+) 0.0035 102	---
JUNM	1.23(1) 0.0042 300	1.23(+) 0.0042 300	---	---	---	---	---	---
JUNR	---	2.95(+) 0.0095 147	2.95(+) 0.0095 147	---	2.95(3) 0.0095 147	3.00(4) 0.0106 83	2.95(+) 0.0095 147	---
SALM	1.39(1) 0.0184 45	1.06(1) 0.0103 36	1.63(1) 0.0141 12	1.63(+) 0.0141 12	---	1.67(4) 0.0141 21	2.62(5) 0.0211 16	---
SALT	1.86(1) 0.0175 37	2.21(1) 0.0169 18	3.20(1) 0.0183 10	3.20(+) 0.0183 10	---	3.20(4) 0.0183 10	3.20(+) 0.0183 10	---
SCYN	---	---	8.29(+) 0.0492 6	---	---	4.00(4) 0.0267 7	---	---
SPAT	1.03(1) 0.0025 409	0.85(1) 0.0019 327	1.65(1) 0.0019 236	---	2.58(2) 0.0026 236	1.88(4) 0.0016 333	1.88(+) 0.0019 333	---

Data arranged in vertical triplets:

h, stem height below inflorescence, in feet
D, base diameter, in feet
N, number density, in inverse square feet

Parenthetical references indicate data source:

1 = Hardisky and Reimold, 1977
2 = Monte, August 1983
3 = Kruczynski, Subrahmanyam, Drake, 1978
4 = Hopkinson, Gosselink, Parrondo, 1980, Diameters extrapolated
5 = Turner and Gosselink, 1975, Diameters extrapolated
+ = Extrapolated Data
--- = Insignificant amounts of this plant type in the region

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D.3.6.4 Error Messages

While using the WHAFIS program, the Mapping Partner may encounter the error messages listed below.

- "AS card ground elevation less than SWEL, should use other type card, job dumped."

  Only use AS (above surge) line when the ground elevation is above the SWEL. Can otherwise use IF, OF, BU, DU, VE, or VH.

- "Ground elevation greater than surge elevation encountered, job dumped."

  If ground elevation is above surge elevation, AS card should be used.

- "Average depth less than or equal to zero, job dumped."

  The water depth must be greater than zero or a wave height cannot be computed. Check the SWEL and the ground elevation if point of job dump is not the last point along the transect profile.

- "The above card contains illegal data in the first 2 columns."

  Check input data for incorrect values or input within wrong columns. Aside from the title line, the first two columns in each line should contain the card identifiers.

- "Transmitted wave height at last fetch or obstruction = ______ which exceeds 0.5."

  Code the transect profile up to the inland limit where ground elevation intersects the SWEL so that wave height should decrease to zero. If the scope of work ends at the corporate limits before the ground elevation meets the SWEL, this message can be ignored.

- "Array dimensions exceeded. Job dumped."

  Size of the array is limited and the number of input parameters has exceeded the array. Check the number of input parameters at the location where the job dumped.

- "Invalid data in field 1 of IF card," etc.

  Check input data to make sure that data are in correct columns.

- "Wave period less than or equal to zero in subroutine fetch. Abort run."

  Either a fetch length or a wave period must be input for the program to run properly. Check input data.

- "Invalid data in field 3 or field 5 of VH card."
  Check input data.
- "Invalid data in field 4 of VH card."

  Check input data.

- "Invalid data in field 3 of MG card."

Check input data. The fraction of vegetated area covered by the stated plant type should be a decimal number between 0.0 and 1.0.

- "Missing MG card or incorrect data in field 6 of VH card."

  A MG card must always follow the VH card. Field 6 of the VH card pertains to the number of plant types, and one MG card is required for each plant type.

- "Invalid input data."

  Check input data for invalid characters, such as an O instead of a zero. Check to be sure that all data are in their correct columns.

- "Fcov was found to be negative for plant type = _______."

  Check input data to be sure that the decimal fraction of the vegetated area covered by the plant type is not negative.

- "Ncov is .LE. zero in Sub.Lookup when it should be .GT. zero. Abort run."

  Check input for number of plants covering the area.

- "The first card is not an IE card, this transect is aborted. Continued to next transect."

  The first card after the title line must always be an IE card. Check input data.

- "**** The surge elevation at this station (stationing ____), which is ____ card, is less than the ground elevation. The interpolation process is continued. *** Please double check the surge and ground elevations in the vicinity of this station!!!!!!"

  The surge elevation should not be below the ground elevation. If the interpolated surge elevation is interpolated below the ground elevation, insert additional cards to specify surge and ground elevations and use an AS card if necessary.

- "Interpolation line cuts off more than two portions of high ground ridge. This transect is aborted, re-assign 1-percent-annual-chance elevations at high ground stations."

  When the interpolated value falls below the ground elevation, insert additional cards to better model the area and set the SWEL equal to the ground elevation where appropriate. Insert AS cards as necessary.

- "**** Unreasonable high ground elevation at station ____ which is ____ card. This transect is aborted, continued to next transect. **** Double check the surge and ground elevations in the vicinity of this station. If the ground elevations are correct, either assign a higher surge elevation or use AS cards."

  Add additional input data as necessary to better define the ground elevation and surge elevation in this area.

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D.3.6.5 Output Description

The output of the program provides all the data necessary for plotting the BFEs and flood insurance risk zones along the transect. The output is in six parts:

Part 1 - Input

This is a printout showing all input data lines and the parameters assigned to each line, both manually and by default. This is followed by a more detailed printout with column headings for each input data line. When VH and MG Lines are used, a separate insert will be printed directly beneath the MG Line showing any default values supplied by the computer.

Part 2 - Controlling Wave Heights, Spectral Peak Wave Period, and Wave Crest Elevations

This is a list of the calculated controlling wave heights, spectral wave peak periods, and wave crest elevations at the end point of each fetch and obstruction of the input, and at calculation points generated between the input stations.

Part 3 - Location of Areas Above 1-Percent-Annual-Chance Surge

This is a list of the locations of areas where the ground elevation is greater than the 1-percent-annual-chance stillwater (surge) elevation. Only areas identified by AS lines are listed.

Part 4 - Location of Surge Elevations

This is a list of the 10- and 1-percent-annual-chance stillwater (surge) elevations and the stationing of the points where each set of SWELs first becomes fully effective.

Part 5 - Location of V Zones

This is a list of the locations of the V/A Zone boundary and locations of the V Zone areas relative to these boundaries. The stationing is given for each V/A Zone boundary. The locations of the V Zone areas in relation to these boundaries are given as windward or leeward of the boundary.

Part 6 - Numbered A Zones and V Zones

This is a list of the zone data needed to delineate the flood hazard boundaries on the FIRM. The location of a flood zone boundary and the wave crest elevation at that boundary are given on the left. Between the boundary listings are the zone designations and FHFs. Under FEMA's Map Initiatives Procedure guidelines, all numbered V and A Zones should be changed to VE and AE Zones, respectively (elevations will not change), and the FHFs can be ignored (FEMA, 1991). When the same zone and elevation are repeated in the list, they should be treated as a single zone.

[February 2002]

D.3.7 Mapping of Flood Elevations and Zones

This subsection discusses procedures for reviewing the initial model results and identifying flood insurance risk zones, and provides guidance for depicting the analysis on the FIRM.

[February 2002]

D.3.7.1 Review and Evaluation of Basic Results

The results of the technical analyses performed for the FIS or map revision determine the special flood hazards shown on the FIRM. The coastal hazards mapped on the FIRM depict the effects of erosion on overland wave propagation, the impact of steep beach slopes and bluffs on wave runup elevation, and the areas subject to high velocity wave hazards (V Zones). Because the FIRM is used for floodplain management and flood insurance determination, the Mapping Partner shall ensure the SFHAs are mapped with as much accuracy as possible.

With the results of the various analyses at hand, the Mapping Partner shall place flood elevations and zones on the work map or up-to-date topographic survey map, after first reviewed them for their consistency with the terrain and conditions they represent and with historical data. In using the models, it is possible to forget that the transects represent real shorelines of sandy beaches, rocky or cohesive bluffs, wetlands, etc., being subjected to extremely high water, waves, and winds. The Mapping Partner shall review the results of the analyses to determine if they are a reasonable representation of the coastal areas being modeled.

Although historical data from a storm closely approximating the base (1-percent-annual-chance) flood are seldom available, flood data for less intense storms will still indicate, at a minimum, what areas should be in flood zones. For instance, if a storm produced an extreme flood that caused structural damage to houses 100 feet from the shoreline, yet the flood was below the 1-percent-annual-chance flood SWEL, a reasonable Zone VE width would be at least 100 feet. Similarly, houses more than 100 feet from the shoreline that are flooded but not structurally damaged by the same storm must be at least in a Zone AE, AH, or AO. If the analyses of the 1-percent-annual-chance flood produce flood zones and elevations indicating lesser hazards than those recorded for a more common storm, the Mapping Partner shall reevaluate the analyses. There may be an explanation for the inconsistency (other than an error in the input data); for instance, a new coastal structure may act to reduce flood hazards locally or a big storm may have significantly altered the terrain. A field check should be undertaken to determine whether such an explanation exists.

If no explanation for the inconsistency is apparent, the Mapping Partner shall examine the data input to the models including checking that the SWELs, wave heights, wave periods, and fetch lengths were input correctly and are consistent with the historical data. A further field check could examine whether buildings or structures modeled would be destroyed by the storm or whether the buildings are on pilings above the flooding.

The Mapping Partner also shall evaluate the results of the erosion assessment by comparing the eroded profile to past effects, whether in the form of profiles, photographs, or simply descriptions. A general idea of what happened previously can be sufficient. Judgment and experience must be used to project previous storm effects to the 1-percent-annual-chance flood conditions and to ensure that the eroded profile is consistent with previous events.

The main point emphasized here is that the results are not to be blindly accepted. Many uncertainties and variables in coastal processes may occur during an extreme flood, and many possible adjustments to methodologies for treating such an event may be appropriate. The validity of any model is demonstrated by its success in reproducing recorded events. Therefore, the model results must be in basic agreement with past flooding patterns and results, and historical data must be used to evaluate these results.

[February 2002]

D.3.7.2 Identification of Flood Insurance Risk Zones

Interpretation and accurate delineations of the hazards on the maps are the final critical elements in a coastal flood hazard study. The transect used in the wave elevation determination and the resulting wave analyses, whether for wave height or wave runup, is the tool by which the results can be mapped. Mapping Partner shall identify the flood zones and BFEs should be identified on each of the transect plots before transferring the information and delineating the hazard zones and BFEs on the work maps. It should be noted that because of changes in the NFIP in 1988 that redefined the Coastal High Hazard Area and incorporated wave runup hazards, Part 6 of the WHAFIS output, discussed in Section D.3.6, is no longer used to plot zones on the work maps.

It is important to understand the interrelationship of the three key elements in determining the flood hazard zone and BFE. These elements are the existing transect ground profile, the eroded transect ground profile, and the wave envelope. The existing transect ground profile may be modified by the presence of erosion forces along the shoreline, if appropriate, in which case the flood hazard zone depicted by the transect and wave analyses results may not appear to reflect the topography shown for existing conditions with ground elevations higher than the BFE. The eroded transect ground profile, developed using treatment described in Subsection D.3.4, must be used in the wave analyses described in Subsections D.3.5 and D.3.6. The BFEs and the topography shown on the work maps may differ from those produced by the erosion treatments for a shoreline reach and the wave analyses. This is because the topography of the work maps does not reflect the erosion of the shoreline determined as part of the coastal FIS or map revision request. To clarify areas where these discrepancies exist, the Mapping Partner shall provide a description of the areas subject to erosion treatments either in the coastal FIS Report or in the supporting engineering report for a map revision request.

The wave envelope is the most important of the three elements for identifying the flood hazard zone. The wave envelope is a combination of representative wave runup elevation and the wave crest profile determined by the wave results computed using the WHAFIS program. The wave crest profile is plotted on the final transect ground profile (with or without the effects of erosion) based on the results computed and shown in Part 2 of the WHAFIS output. For wave runup elevation results, a horizontal line is extended seaward from the computed runup elevation to its intersection with the wave crest profile. This determines the wave envelope profile for the results combined from the WHAFIS wave height analysis and the RUNUP 2.0 wave runup analysis, as shown in Figure D-46. If the runup elevation is greater than the maximum wave crest elevation, the wave envelope will be a horizontal line at the runup elevation. Conversely, if the wave runup is negligible or was not modeled because of coastal processes and shoreline conditions that prevent significant runup from occurring, the wave crest profile alone will become the wave envelope.

Before transferring the established wave envelope information from each transect onto the work maps, it is important to understand the NFIP coastal flood zones and how to determine their location along the transect plot. The descriptions are as follows:

Zone VE - Coastal High Hazard Areas where wave action and/or high velocity water can cause structural damage in the base (1-percent-annual-chance) flood. The three criteria for determining a Zone VE area are: (1) the area where 3 foot or greater wave height could occur (this is the area where the WHAFIS wave crest profile is 2.1 feet or more above the SWEL), (2) the area where the eroded ground profile is 3 feet or more below the representative runup elevation, and (3) the primary frontal dune, by definition. Subdivided into elevation zones with BFEs assigned.

Zone AE - Areas of inundation by the base (1-percent-annual-chance) flood, including wave heights less than 3 feet and runup elevations less than 3 feet above the ground. Also subdivided into elevation zones with BFEs assigned.

Zone AH - Areas of shallow flooding or ponding, with water depth equal to 3 feet or less. Usually not subdivided, but a BFE is assigned.

Zone AO - Areas of "sheet-flow" shallow flooding where overtopping water flows into another flooding source. Assigned with 1-, 2-, or 3-foot depth of flooding.

Zone X - Areas above base (1-percent-annual-chance) flood inundation. On the FIRM, shaded Zone X is inundated by the 0.2-percent annual chance flood, unshaded Zone X is above 0.2-percent annual chance flood.

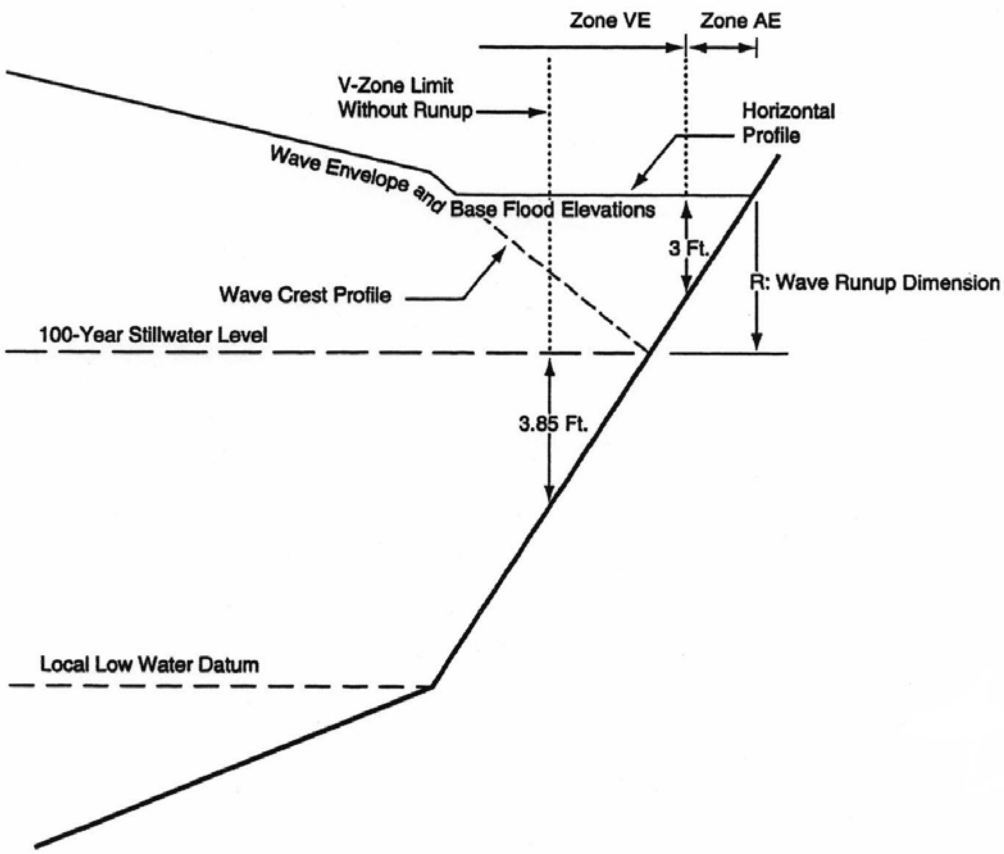

Figure D-46. Wave Envelope Resulting from Combination of Nearshore Crest Elevations and Shore Runup Elevation.

The first step in identifying the flood insurance risk zones on the transect is locating the inland extent of the VE Zone, also known as the VE/AE boundary. Once the Mapping Partner has identified the VE Zone limits for each of the three criteria described above, the Mapping Partner shall place the VE/AE boundary at the location that is furthest landward. The AE Zone will extend from the VE Zone limit to the inland limit of the 1-percent-annual-chance flood inundation, which is a ground elevation equal to the representative runup elevation, or the 1-percent-annual-chance SWEL if runup is negligible or not included in the wave analyses. Additional areas of shallow flooding or ponding for the 1-percent-annual-chance flood event can be designated as Zone AH or Zone AO. All areas above the 1-percent-annual-chance flood inundation are Zone X.

The Mapping Partner shall then subdivide the AE and VE Zones into elevation zones with whole-foot BFEs assigned. Ideally, to help in floodplain management and insurance determinations for buildings and property, the Mapping Partner shall establish an elevation zone for every BFE in the wave envelope. However, the FIRM scale may limit the number of zones that can be mapped. For the FIRM to be legible, there must be a minimum width for the zones. For coastal areas, the minimum zone width is 0.2 inch. For identifying elevation zones on the transect, the minimum width is 0.2 times the final FIRM scale; for example, 80 feet for a FIRM at a scale of 1 inch equals 400 feet, 100 feet for a FIRM at a scale of 1 inch equals 500 feet.

The Mapping Partner shall not subdivide the horizontal runup portion of the wave envelope, if any; the runup elevation, rounded to the nearest whole foot, is the BFE. However, the Mapping Partner shall subdivide the WHAFIS wave crest profile. Generally, the VE Zone is subdivided first. Initially, the Mapping Partner shall mark the location of all the elevation zone boundaries on the transect. Because whole-foot BFEs are being used, these must always be at the location of the half-foot elevation on the envelope.

The Mapping Partner shall combine elevation zones that do not meet the minimum width criterion with an adjacent zone or zones to yield an elevation zone that is wider than the minimum. The BFE for this combined zone is a weighted average of the combined zones. Often in subdividing VE Zones, the maximum BFE is located just inside the mapped shoreline, and the remainder of the VE Zone is then subdivided into minimum width elevation zones.

The Mapping Partner shall subdivide the AE Zone, if it is wide enough, in the same manner. If the total AE Zone is less than the minimum width, the lowest elevation VE Zone is usually assigned to that area. This situation typically occurs for steep or rapidly rising ground profiles, and it is not unreasonable to designate the entire inundated area as a VE Zone.

Relatively low areas inland of the AE Zone may be subject to shallow flooding or ponding of flood water and designated as AH or AO Zone. Such designations can be relatively common landward of coastal structures and dunes, where wave overtopping occurs.

Identifying appropriate zones and elevations may require particular care for dunes, given that the entire primary frontal dune is defined as Coastal High Hazard Area. Although the analyses may have determined a dune will not completely erode and wave action should stop at the retreated duneface with only overtopping possibly propagating inland, the entire dune is still designated as a VE Zone. The BFE at the duneface is assigned for the remainder of the dune.

It may seem unusual to use a BFE that is lower than the ground elevation, although this is actually fairly common. Most of the BFEs for areas where the dune was assumed to be eroded are also below existing ground elevations. In these cases, it is the VE Zone designation that is most important to the NFIP; current regulations require structures to be built on pilings and prohibit alterations to the dune.

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D.3.7.3 Mapping Procedures

The final work maps prepared from the results of the coastal FIS or map revision request will be used to produce a new or revised FIRM for the affected community. The work map is essentially the base map selected for the study area, as described in Subsection D.3.2, and the depiction and delineation of the coastal flood hazards that reflect the results of the wave elevation determinations and flood zones established for each respective area. The Mapping Partner shall seta the work map up with contour lines, buildings, structures, vegetation, and transects used in the wave analyses clearly and accurately located.

The Mapping Partner shall transfer the flood zones and wave elevations identified on the transects to the work maps and interpolate the boundaries between the transects. The interpolation of the results at the transects and between the transects for the results of the wave height and wave runup analyses involves judgment and skill in reading the topographic and land cover information shown on the work maps. The time and effort put forth to determine the wave elevations will be negated if the results cannot be properly delineated on the work maps and shown on the FIRM. Because roads are the only fixed physical features shown on the FIRM, it is very important that other features and the flood zone boundaries are properly located on the work maps in relation to the centerline of the roads as they will appear on the FIRM. Other important considerations for mapping the results of the coastal FIS or map revision request discussed below include shoreline fluctuations, flood zone widths, interpolation of the transitions between zones for the represented transects, and the depiction and delineation of the Zone X shaded special flood hazard areas in areas subject to wave runup hazard.

An important but potentially ambiguous map feature is the depicted shoreline in the study area. Great Lakes shorelines are subject to large position changes, given shore erosion or accretion along with the considerable range in mean lake levels. The shoreline location may vary among the transects analyzed because of historical erosion or accretion not shown or accounted for on existing maps, but some clearly designated shoreline should be used for the work maps. For Great Lakes studies, the Mapping Partner shall ensure the depicted shoreline corresponds to the land intercept of Low Water Datum, as given in Table D-12 and usually shown on USGS maps. (It is customary to delineate flood zones only landward of the shoreline.)

The Mapping Partner shall transfer the identified elevation zones for each transect to the work maps, locating the boundaries along the transect line so that boundary lines can be interpolated between transects, assuring that the boundaries are marked at the correct location. Because of the erosion assumptions, the location of the elevation 0.0 NGVD shoreline changes on the transect but not the work maps. The transect profile is used to determine the location of the zone change in relation to a physical feature, such as a ground contour, road, the back side of a row of houses, 50 feet into a vegetated area, etc. The boundary line along this feature for the area represented by that transect is then delineated.

The Mapping Partner shall check the widths of the zones being delineated carefully; if they narrow to less than 0.2 inch, they should be tapered to an end. Likewise, if an averaged elevation zone becomes much wider, it may be possible to break it into two elevation zones, both wider than 0.2 inch. Consideration of the final map scale of the FIRM to be produced from the work maps will help in determining how the zones should be combined and averaged.

One of the more difficult steps in delineating coastal flood zones and elevations is the interpolation and transition between transect results. Good judgment and an understanding of typical flooding patterns are the best tools for this job. The first step is to locate on the work maps any area of transition that is not exactly represented by either transect. The next step is to delineate the flood boundaries for each transect up to this area. Then consideration should be given to how a transition can be made across this area to connect matching zones, and still have the boundaries follow logical physical features. If there are other transects that are similar to this area, they could give an indication of flooding. Sometimes the elevation zones for the two contiguous transects are not the same; thus, some zones may have to be tapered to an end, or enlarged and divided in the transition area.

Communities with significant flooding hazards from wave runup may have one transect representing more than one area because the areas have similar shore slopes. In this case, the different areas are identified, and the results of the typical transect delineated in each area. Transition zones may be necessary between areas with high runup elevations to avoid large differences in BFEs and to smooth the change in flood boundaries. These zones, which should be fairly short, should cover the shore segment with a slope not exactly typical of either area. The transition elevation is determined by examining runup transects with similar slopes and using good judgment. Transition zones should not be used if there is a very abrupt change in topography, such as is found at the end of a structure.

Lastly, Mapping Partner shall map the Zone X (shaded) areas. Areas below the 0.2-percent annual chance SWEL and not covered by any other flood zone are designated Zone X shaded and shown on the FIRM. Often the maximum runup elevation is higher than the 0.2-percent annual chance elevation; thus, there will be no shaded Zone X in that area. The Mapping Partner shall designate all other areas as Zone X without any shading.

These *Guidelines* were compiled to give guidance in the preparation of coastal FISs and map revision requests. The collection of accurate and representative data, the correct application of the models, the evaluation and comparison of the results to historical data, and the proper delineation of flood elevations and zones will produce a FIRM that is both technically correct and directly usable for the intended purposes.

During all steps of the study, especially the mapping, the final product and its purposes should be remembered: the FIRM is used to determine flood insurance premiums and regulate building standards.

Because flood elevations are rounded to the nearest whole foot, there is no reason for spending hours to resolve a minor elevation difference. Also, because structures or proposed structures must be located on the FIRM, an attempt should be made whenever possible to smooth the boundary lines and to follow a fixed feature such as a road. In preparing the FIS, not only must the mapped results be technically correct, but the FIRM must be easy for the local insurance agent, building inspector, or permit officer to use.

Additional criteria and submittal requirements are documented in the Certification forms for Study Contractors (SC-1) and Application/Certification form 5 (MT-2) for map revision requests.

[February 2002]

D.3.8 Required Documentation

The Mapping Partner shall fully document the coastal flood hazard determination for each affected community. Because FIS Reports and FIRMs form the basis of Federal, State, and local regulatory and statutory enforcement mechanisms and are subject to administrative appeal and litigation, Mapping Partners shall ensure that all technical processes and decisions are recorded and documented. The FIS Report may not contain all the documentation that would be needed for a response in the event that the study results are questioned. Therefore, the Mapping Partner shall prepare an engineering report for each study. This report will provide detailed data needed by FEMA or the community to reconstruct or defend on technical grounds the study results. The minimum information required for the engineering report are summarized below.

Basic Data.

In this section, the Mapping Partner shall include all contacts made to obtain data for the study. All basic data used must be fully referenced and, if possible, reproduced in the report. All historical flood information must be documented in this section, even if the Mapping Partner did not use the information in quantitative analyses.

Transects

Each transect must be plotted separately and show the erosion assessment, input data for wave models, wave envelope, and zone determination.

Model Input and Output

The Mapping Partner shall provide computer printout listings for input and output data for both the Wave Runup and Wave Height Models for all the transects. These listings must be keyed to the transect location map and transect plots.

Study File

During the course of the study, the Mapping Partner shall maintain a file containing records of all coordination, activities, and decisions. This is especially important where nonstandard approaches were used and engineering judgment played a significant role. The Mapping Partner shall ensure this file meets the requirements for a Technical Support Data Notebook as documented in Appendix M of these Guidelines.

[February 2002]

D.3.9 Open Coast Flood Elevations and Wave Information

As discussed in Subsection D.3.2, the draft of "Basic Analyses of Wave Action and Erosion with Extreme Floods on Great Lakes Shores" (Dewberry & Davis, 1995) concluded from historical evidence that extreme floods were usually accompanied by the local 1/2-year wave condition on Lake Ontario, or by the 3-year wave condition on Lakes Erie, Huron, Michigan, and Superior. Examples of appropriate wave conditions derived for numerous sites on each of the Great Lakes are presented in Figures D-47 through D-56 and in Tables D-23 through D-27.

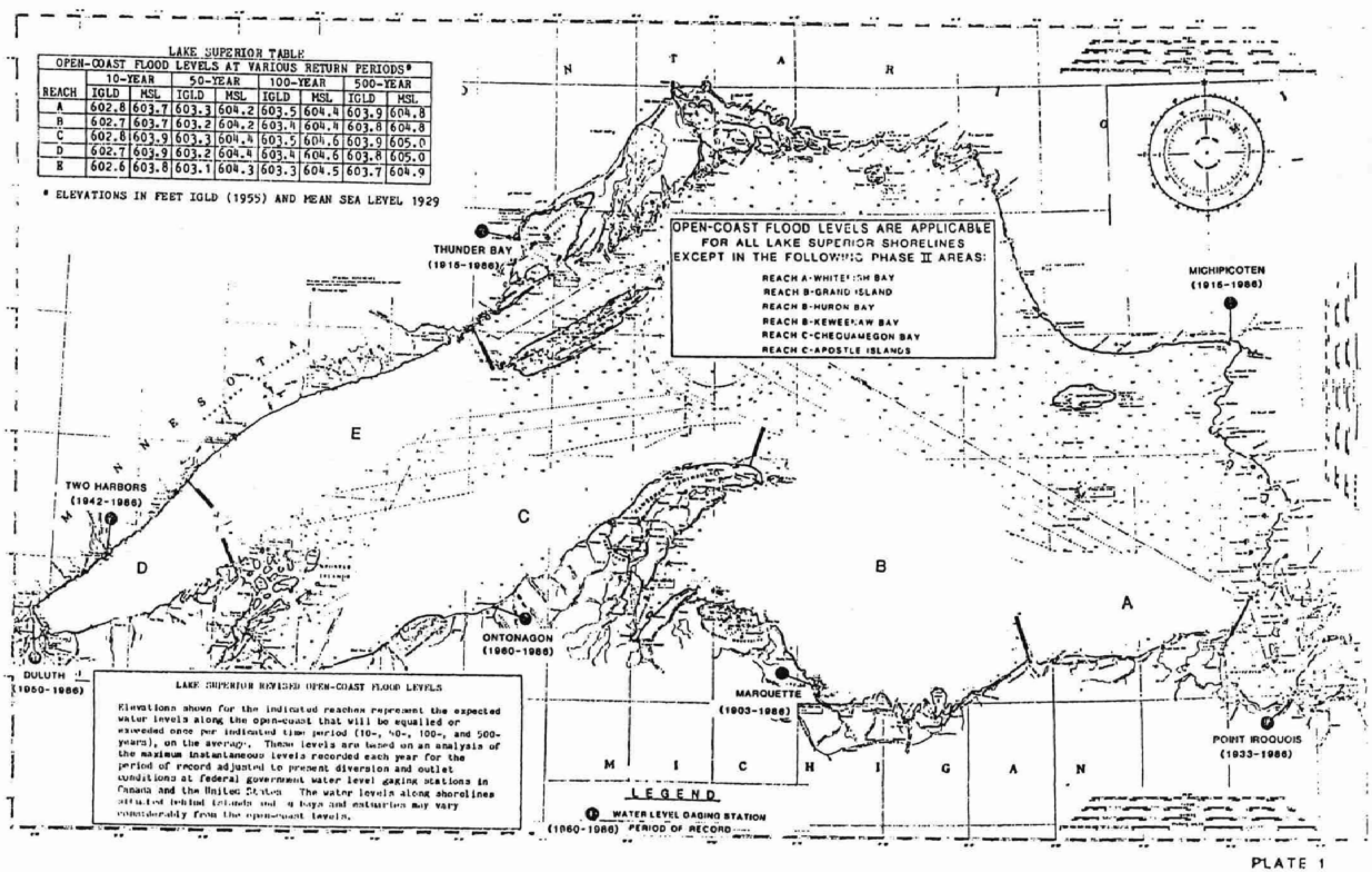


Figure D-47. Lake Superior Table and Map of Open Coast Flood Levels (USACE, 1988).

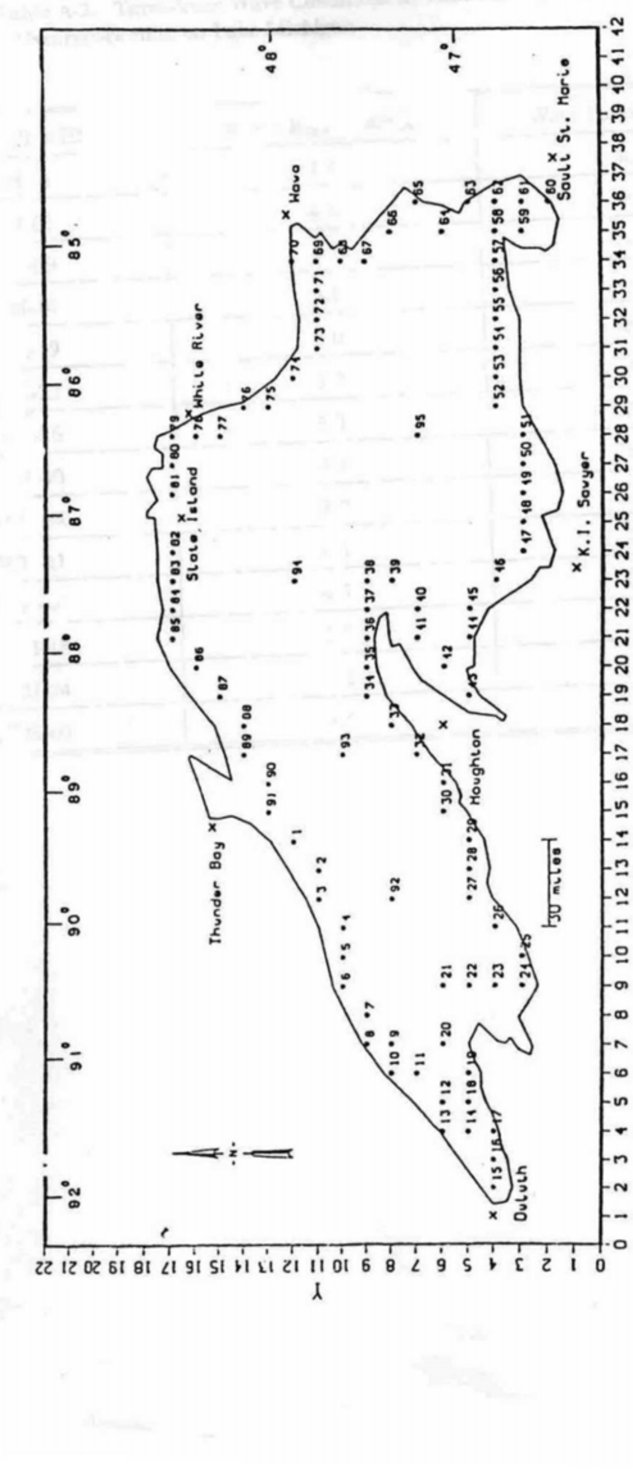
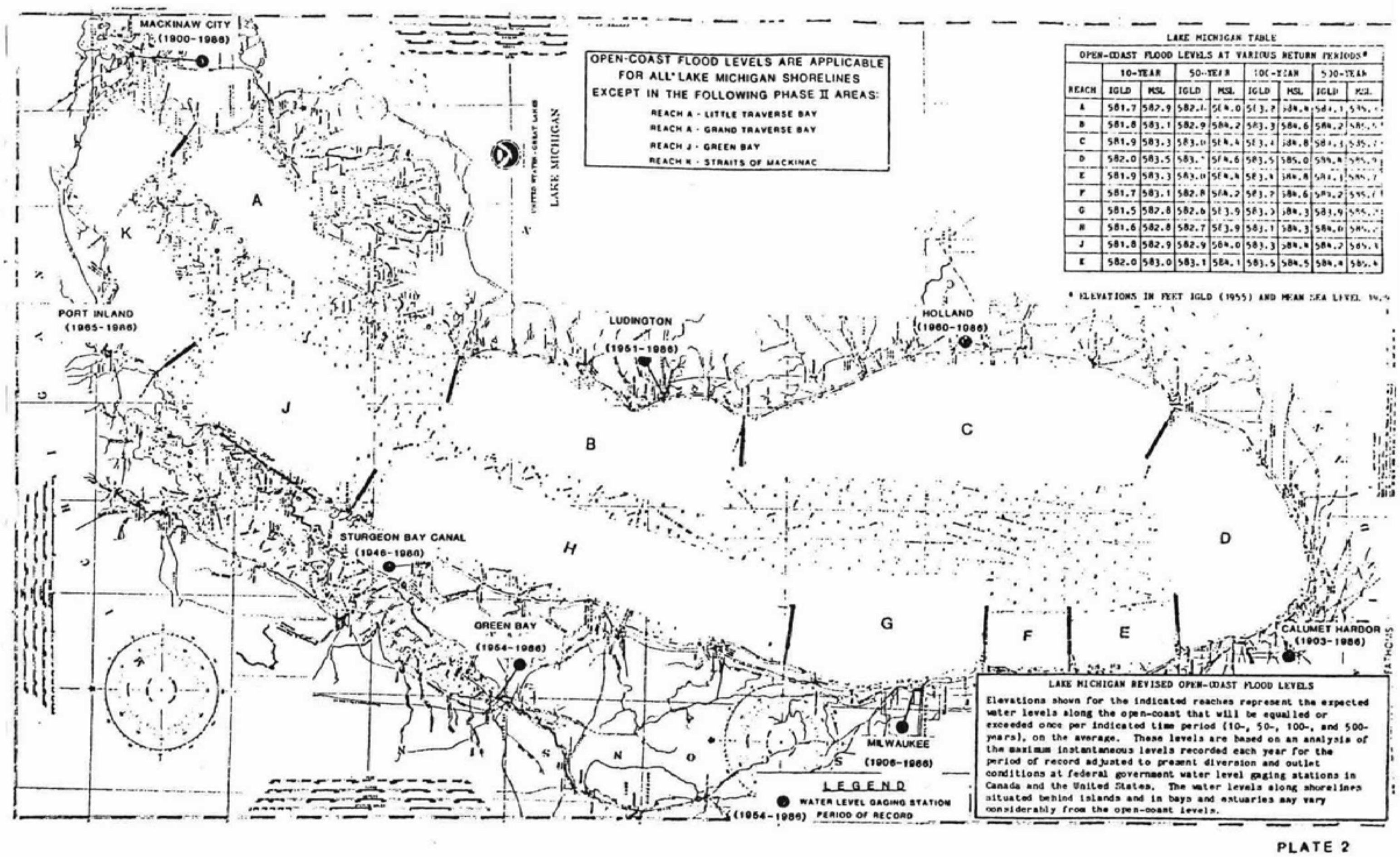


Figure D-48. Station Location Map for Lake Superior Wave Information Stations.

Table D-23. Three-Year Wave Conditions as Hindcast for Selected Nearshore Sites on Lake Superior

HINDCAST SITE ID	WAVE HEIGHT (METERS)	WAVE PERIOD (SECONDS)
SUPER-05	6.0	10.0
SUPER-13	5.8	10.0
SUPER-15	3.7	7.1
SUPER-23	4.3	--
SUPER-29	5.0	9.1
SUPER-35	5.9	--
SUPER-42	5.2	--
SUPER-47	7.7	11.1
SUPER-54	6.2	--
SUPER-60	4.5	7.7



LAKE MICHIGAN TABLE

OPEN-COAST FLOOD LEVELS AT VARIOUS RETURN PERIODS*								
	10-YEAR		50-YEAR		100-YEAR		500-YEAR	
REACH	IGLD	MSL	IGLD	MSL	IGLD	MSL	IGLD	MSL
A	581.7	582.9	[illegible]	584.0	[illegible]	[illegible]	[illegible]	[illegible]
B	581.8	583.1	582.9	584.2	583.3	584.6	584.2	[illegible]
C	581.9	583.3	583.0	584.4	583.4	584.8	[illegible]	[illegible]
D	582.0	583.5	[illegible]	584.6	583.5	585.0	[illegible]	[illegible]
E	581.9	583.3	583.0	584.4	583.4	584.8	[illegible]	[illegible]
F	581.7	583.1	582.8	584.2	583.2	584.6	[illegible]	[illegible]
G	581.5	582.8	582.6	583.9	[illegible]	584.3	583.9	[illegible]
H	581.6	582.8	582.7	583.9	583.1	584.3	584.0	[illegible]
J	581.8	582.9	582.9	584.0	583.3	584.4	584.2	[illegible]
K	582.0	583.0	583.1	584.1	583.5	584.5	584.4	[illegible]

* ELEVATIONS IN FEET IGLD (1955) AND MEAN SEA LEVEL [illegible]

Figure D-49. Lake Michigan Table and Map of Open Coast Flood Levels (USACE, April 1988).

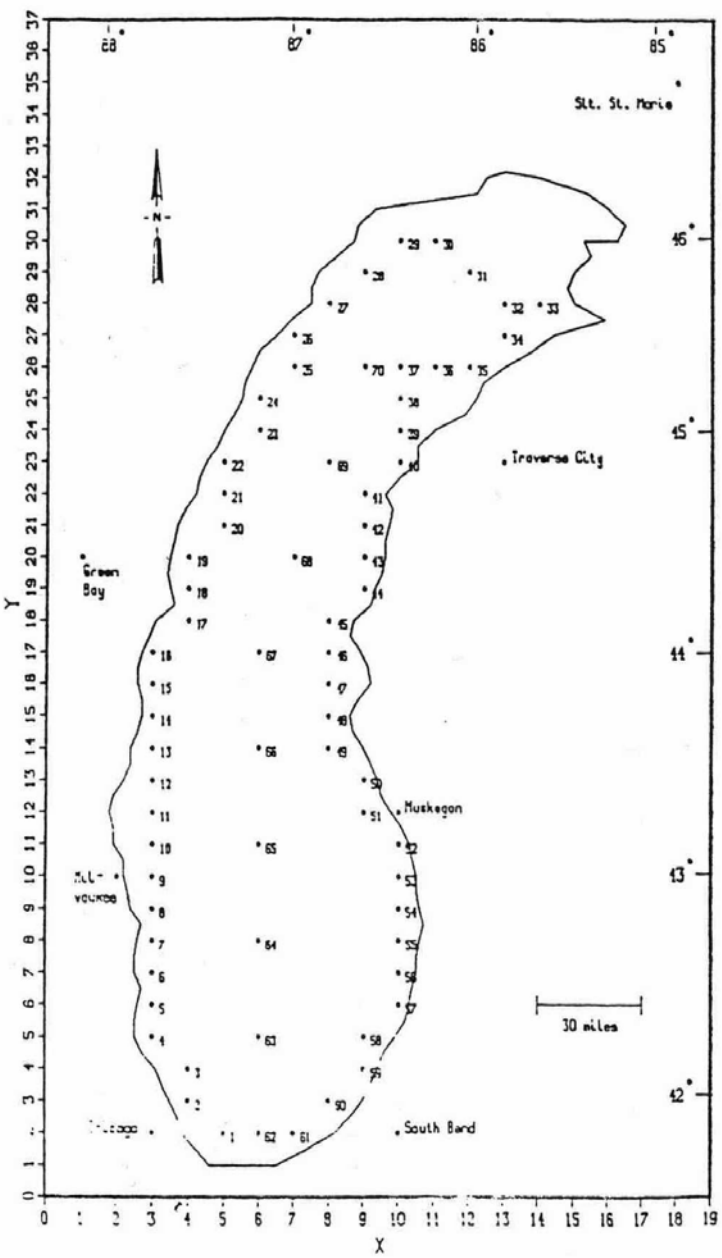
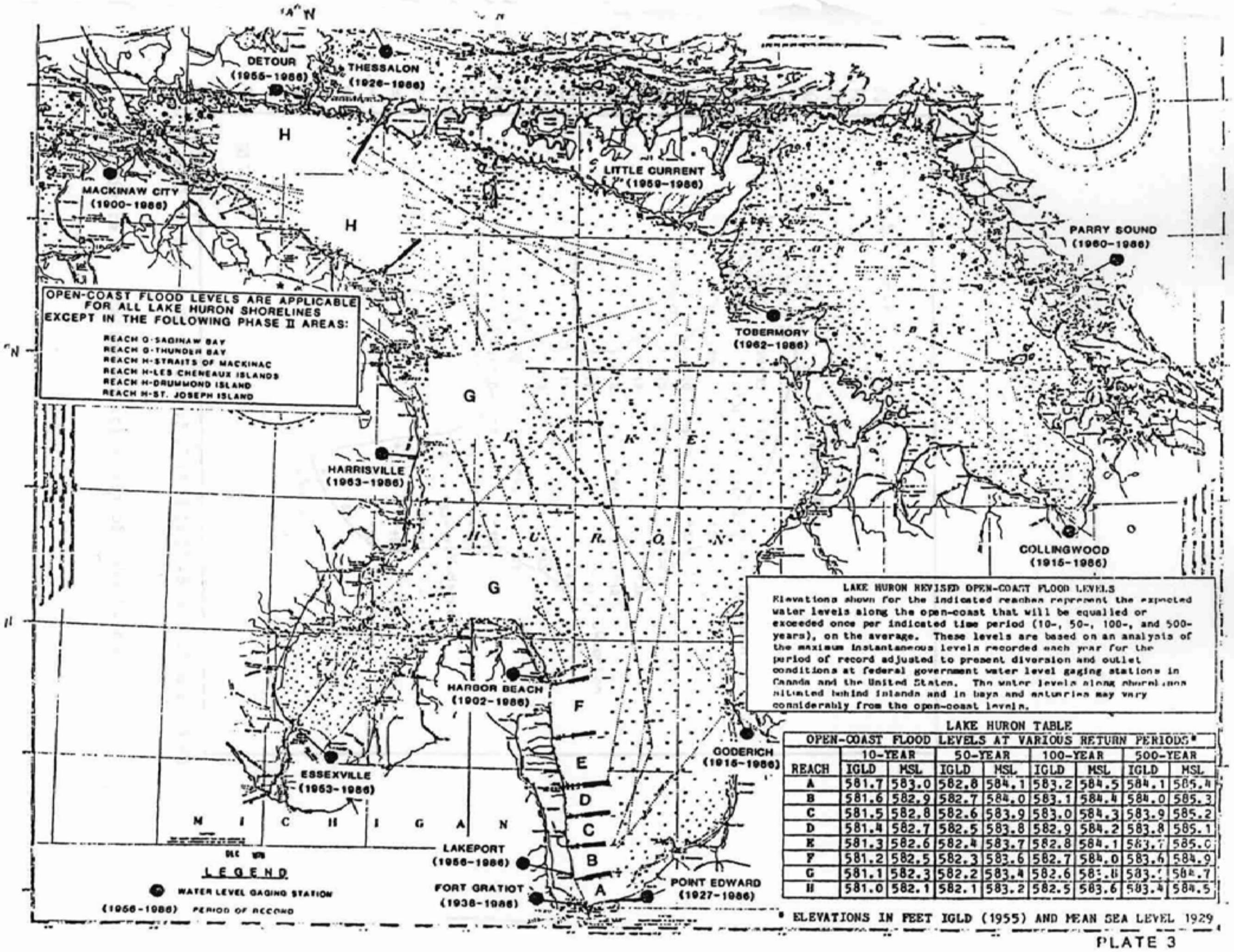


Figure D-50. Station Location Map for Lake Michigan Wave Information Stations.

Table D-24. Three-Year Wave Conditions as Hindcast for Selected Nearshore Sites on Lake Michigan

HINDCAST SITE ID	WAVE HEIGHT (METERS)	WAVE PERIOD (SECONDS)
MICH-01	4.4	9.1
MICH-03	4.6	9.1
MICH-09	4.7	8.3
MICH-14	3.9	--
MICH-19	4.0	8.3
MICH-22	3.7	7.7
MICH-26	3.3	8.3
MICH-30	3.4	8.0
MICH-34	3.7	--
MICH-41	4.1	--
MICH-46	4.7	9.1
MICH-48	5.2	9.1
MICH-54	5.2	9.1
MICH-60	4.5	8.3



LAKE HURON TABLE

OPEN-COAST FLOOD LEVELS AT VARIOUS RETURN PERIODS*								
	10-YEAR		50-YEAR		100-YEAR		500-YEAR	
REACH	IGLD	MSL	IGLD	MSL	IGLD	MSL	IGLD	MSL
A	581.7	583.0	582.8	584.1	583.2	584.5	584.1	585.4
B	581.6	582.9	582.7	584.0	583.1	584.4	584.0	585.3
C	581.5	582.8	582.6	583.9	583.0	584.3	583.9	585.2
D	581.4	582.7	582.5	583.8	582.9	584.2	583.8	585.1
E	581.3	582.6	582.4	583.7	582.8	584.1	583.7	585.0
F	581.2	582.5	582.3	583.6	582.7	584.0	583.6	584.9
G	581.1	582.3	582.2	583.4	582.6	583.8	[illegible]	584.7
H	581.0	582.1	582.1	583.2	582.5	583.6	583.4	584.5

* ELEVATIONS IN FEET IGLD (1955) AND MEAN SEA LEVEL 1929

Figure D-51. Lake Huron Table and Map of Open Coast Flood Levels (USACE, 1988).

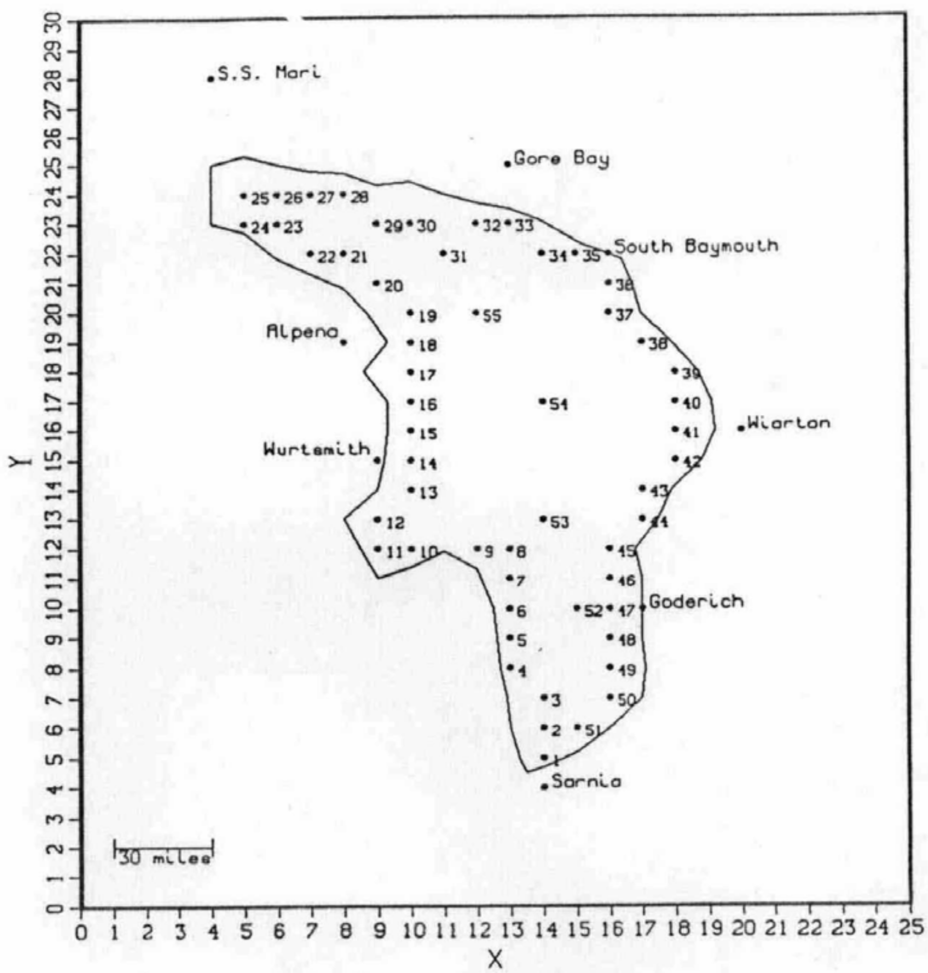


Figure D-52. Station Location Map for Lake Huron Wave Information Stations.

Table D-25. Three-Year Wave Conditions as Hindcast for Selected Nearshore Sites on Lake Huron

HINDCAST SITE ID	WAVE HEIGHT (METERS)	WAVE PERIOD (SECONDS)
HURON-01	6.1	9.1
HURON-02	6.2	10.0
HURON-07	5.6	9.1
HURON-11	6.3	9.1
HURON-12	6.2	9.5
HURON-15	6.1	9.1
HURON-20	5.0	--
HURON-25	4.1	7.7
HURON-26	4.3	9.1

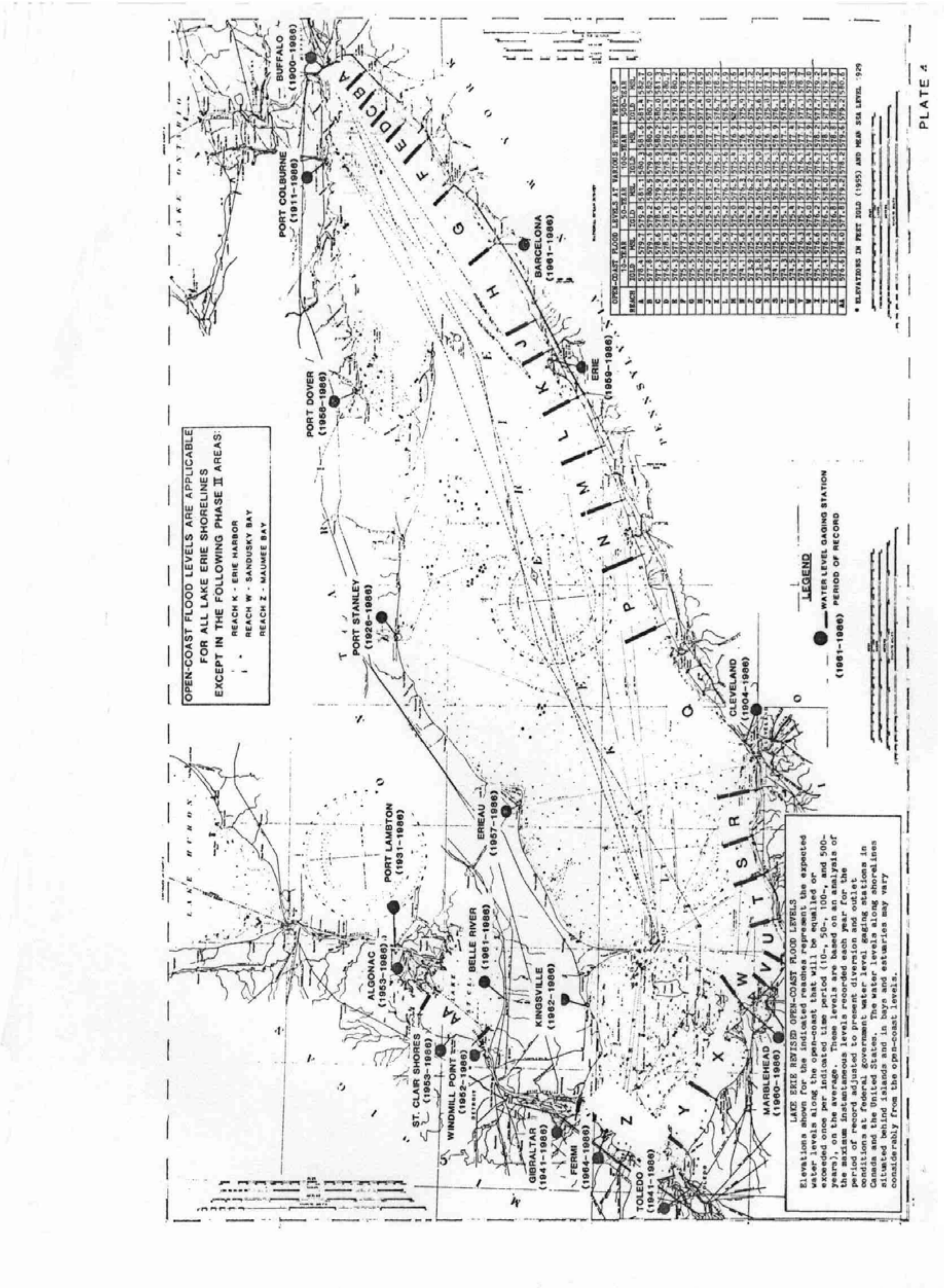


Figure D-53. Lake Erie Table and Map of Open Coast Flood Levels (USACE, 1988).

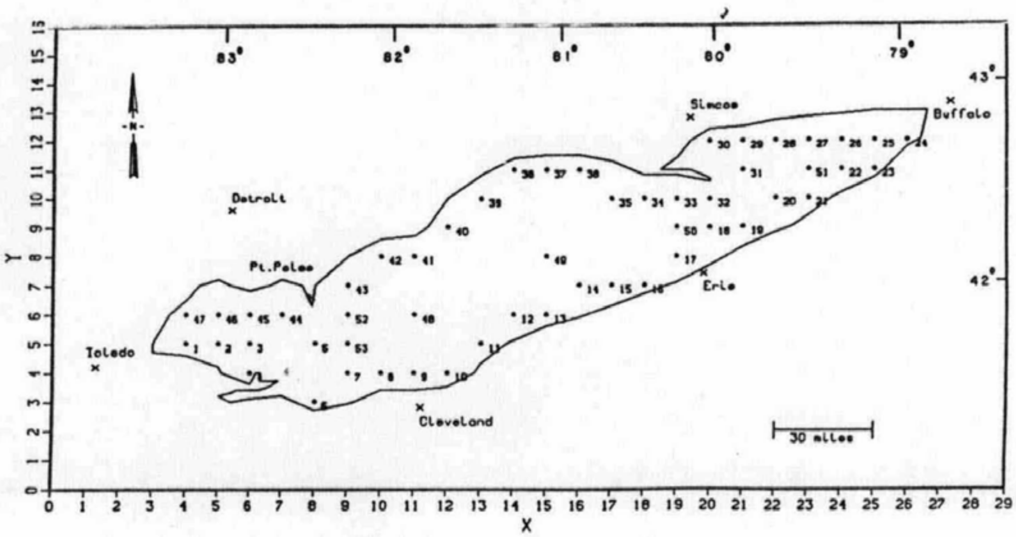
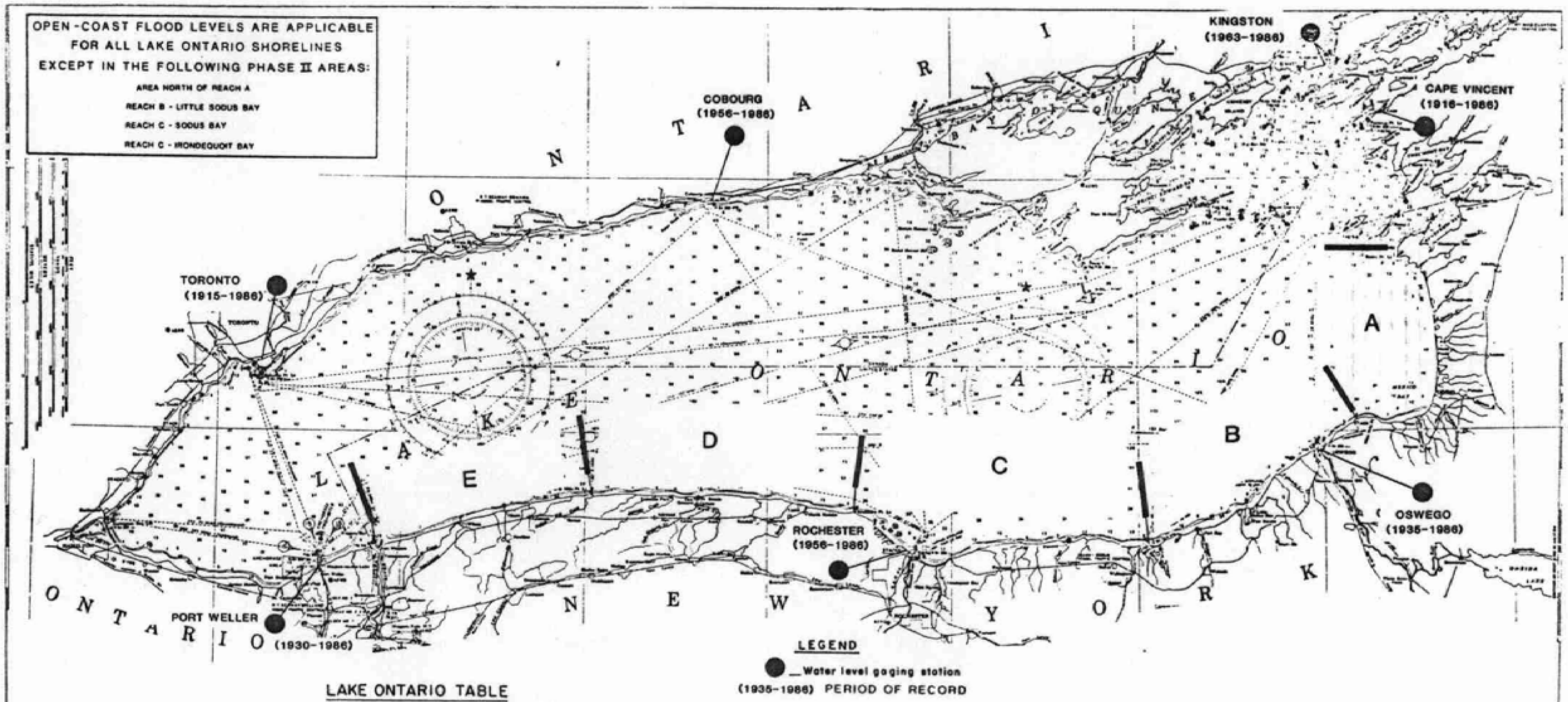


Figure D-54. Station Location Map for Lake Erie Wave Information Stations.

Table D-26. Three-Year Wave Conditions as Hindcast for Selected Nearshore Sites on Lake Erie

HINDCAST SITE ID	WAVE HEIGHT (METERS)	WAVE PERIOD (SECONDS)
ERIE-01	2.0	6.2
ERIE-04	1.9	6.2
ERIE-07	3.3	--
ERIE-10	3.6	7.7
ERIE-12	4.0	8.3
ERIE-15	4.2	--
ERIE-18	4.6	9.1
ERIE-21	4.9	9.1
ERIE-24	4.2	9.1
ERIE-47	1.8	5.6



LAKE ONTARIO TABLE

OPEN-COAST FLOOD LEVELS AT VARIOUS RETURN PERIODS*								
	10-YEAR		50-YEAR		100-YEAR		500-YEAR	
REACH	IGLD	MSL	IGLD	MSL	IGLD	MSL	IGLD	MSL
A	247.5	248.7	248.3	249.5	248.5	249.7	249.2	250.4
B	247.4	248.6	248.2	249.4	248.4	249.6	249.1	250.3
C	247.3	248.5	248.1	249.3	248.3	249.5	249.0	250.2
D	247.2	248.4	248.0	249.2	248.2	249.4	248.9	250.1
E	247.1	248.2	247.9	249.0	248.1	249.2	248.8	249.9

* ELEVATIONS IN FEET IGLD (1955) AND MEAN SEA LEVEL 1929

LAKE ONTARIO REVISED OPEN-COAST FLOOD LEVELS

Elevations shown for the indicated reaches represent the expected water levels along the open-coast that will be equalled or exceeded once per indicated time period (10-, 50-, 100-, and 500-years), on the average. These levels are based on an analysis of the maximum instantaneous levels recorded each year for the period of record adjusted to present diversion and outlet conditions at federal government water level gaging stations in Canada and the United States. The water levels along shorelines situated behind islands and in bays and estuaries may vary considerably from the open-coast levels.

Figure D-55. Lake Ontario Table and Map of Open Coast Flood Levels (USACE, 1988).

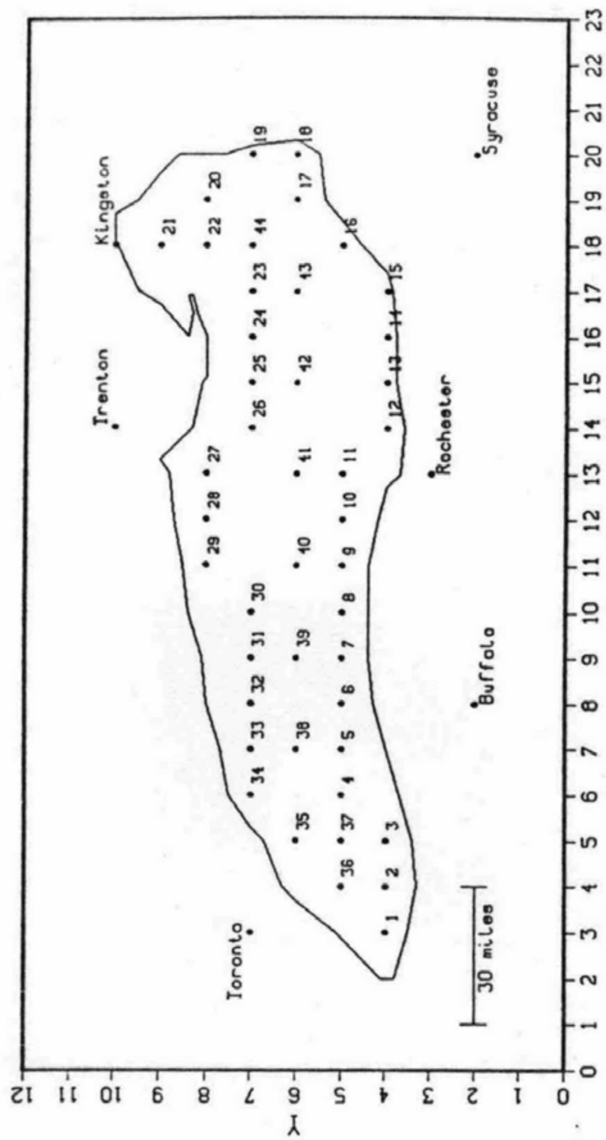


Figure D-56. Station Location Map for Lake Ontario Wave Information Stations.

Table D-27. One-Half-Year Wave Conditions as Hindcast for Selected Nearshore Sites on Lake Ontario

HINDCAST SITE ID	WAVE HEIGHT (METERS)	WAVE PERIOD (SECONDS)
ONT-04	2.7	--
ONT-06	2.9	6.7
ONT-07	3.0	7.1
ONT-11	3.2	7.1
ONT-14	2.6	--
ONT-17	3.2	7.1
ONT-21	2.4	5.9

[February 2002]